III. GRANULAR MEDIA FILTRATION

A. Elements of Design and Operating Conditions

1. Design Approach

Once the filter system has been selected using the guidance provided in Chapter II, the following design features must be established to design facilities for a given application:

- Filtration rate;
- Filter media type, size, and depth;
- Filter configuration;
- Terminal head loss;
- Method of flow control; and
- Backwashing requirements.

After the waste stream has been characterized, the first step is to establish the filtration rate and media type, size, and depth. This is normally done based on regulatory requirements of the governing body having jurisdiction, experience with similar treatment applications, or pilot testing for a specific application, if necessary and cost-effective.

Once the filtration rate for the facility is established, sizing of the facility can be determined based on the required maximum treatment rate. The total filtering area is established and then the number and dimensions for the individual filters are determined. In determining the numbers of filters required, the designer must evaluate the rate to be handled by each filter and the corresponding backwash rate that would be necessary for a certain size of filter. The decision concerning the number and size of the filters has an impact on the individual filter piping and sizing, flow control requirements and operational flexibility of the facility. In addition, the designer must consider the requirement for continuous flow and redundancy in determining an acceptable number of filters. This is discussed further in Section III.A.4.

The configuration of the individual filter must then be decided. Choices must be made concerning the use of single or dual cell filters and the length and width dimensions of the filter cell. The length and width of the filter cell is normally established on the basis of the filter underdrain system and the auxiliary scour system to be used. Manufacturers of the filter equipment components provide guidelines covering the use of their equipment and filter bed layout information in their product literature.

The depth of the filter is established based on the underdrain selection, support gravel requirements, depth of the filter media and the operating water depth above the filter media. There are many different styles of filter underdrains available and the designer must evaluate them on the basis of their hydraulic distribution capabilities, head loss characteristics, materials of construction, and the associated support gravel requirements. In selecting the underdrain system, the designer would normally contact various filter equipment/underdrain suppliers to discuss the process application with them. The available products, options suitable for the application and the relative costs can be established. Once this information is obtained, the designer would use his judgement in selecting what type of underdrain is best suited for the project and is to be used as the basis of design. Support gravel requirements are dictated by the underdrain selection and gravel gradations for the various support gravel layers are provided by the underdrain manufacturer. The gravel is used to prevent plugging of the underdrain system with the media and loss of media. The filter media depth is established based on the process requirements and is set on the basis of experience with similar types of applications or pilot testing for a particular application. The last item to establish is the operating water depth over the filter. The depth over the media should be selected to provide an adequate operating range for the filter. The operating range is dependant on the method of flow control selected and the terminal head loss desired. In the case of constant rate filtration, the method of control most commonly employed, the depth should be set to provide adequate submergence to protect against air binding problems. The range of operating depth above the filter can vary greatly. Additional depth should be provided above the high water level based on plant hydraulics and overflow considerations and to maintain adequate freeboard from the operating level of the filter.

The filter backwashing requirements must be considered in the sizing of the filter since the filter size impacts the sizing of facilities and equipment required for backwash. The size of the filter will dictate the required flowrate and, if applicable, storage volume required to perform a filter backwash. The rate of backwash impacts the sizing of the wastewater troughs, washwater gullets, backwash supply piping and waste backwash drain piping from the filter.

In the design of filtration facilities, the designer must consider each of the features discussed above to develop the facility layout and must have an understanding of the impacts of the various features on one another. In selecting the number and sizing of the filters, the designer must evaluate and consider the operational flexibility of the facility with regard to the plant flow anticipated and the impacts to the auxiliary systems required for the filter backwashing process.

2. Media

a. Type of Media

The filter media provide the surface upon which particles are separated from the waste stream. The media are specified based on material, size, shape, and specific gravity and will be selected based on the waste stream and required effluent quality. The most commonly used granular media materials available for filtration include silica sand, crushed anthracite coal, and garnet or ilmenite (high density sands). Manganese greensand is used when removal of soluble iron and/or manganese is desired. Activated carbon and ion exchange resins may be used to filter out solids in conjunction to their primary utility in removing dissolved compounds. It is important to note that some resin beads are subject to particulate attack, fracturing the resin bead.

Reliable filter performance is dependant on the proper selection and maintenance of filter media and the effective operation of the process. The different types of media can be used alone or in combination with one another. The following media properties are important in establishing the filter performance characteristics:

- Media size and size distribution
- Media density
- Media shape

The hydraulics of filtration as well as filter backwashing are influenced by these properties.

Media Size and Size Distribution
Filter media size affects filter performance in two conflicting ways. Smaller grain size improves particulate removal, but accelerates head loss development and may shorten run time if the filtration cycle is determined by reaching terminal head loss. Conversely, larger grain size causes somewhat poorer particulate removal, but lowers the rate of head loss development.

Filter media size can be defined in several ways. In the United States, filter media is characterized by the effective size and the uniformity coefficient. A sieve analysis of a sample of the media is performed to determine these values. The sieve analysis should be done in accordance with the American Society for Testing and Materials (ASTM) Standard C136-84a, Sieve Analysis of Fine and Coarse Aggregate.

The effective size (ES) is defined as the opening size for which 10 percent by weight of the grains are smaller in diameter. The effective size is determined by reading the particle size from the sieve analysis curve corresponding to the 10% passing value and is typically noted as the d10 size. In general, with relatively uniformly sized particles, the larger media size, the greater the porosity or larger the flow passages through the media.

The uniformity coefficient (U.C.) is a measure of the size range of the media and is defined as the ratio of the opening size for which 60 percent of the grains by weight are smaller compared to the opening size for which 10 percent of the grains by weight are smaller. The uniformity coefficient can be denoted as follows:

$$U.C. = d_{60}/d_{10}$$

The lower the uniformity coefficient, the closer the size range of the particles. The uniformity coefficient is particularly important in the design and operation of dual media filters since it influences the backwash rate required.

Typical ranges of values for the effective size and uniformity coefficient of different types of media are presented in Table A-4.

TABLE A-4
FILTRATION MEDIA EFFECTIVE SIZES AND UNIFORMITY COEFFICIENTS

	Uniformity Coef-ficient	Effective Size (mm)
Silica Sand	1.2 - 1.8	0.4 - 0.8
Anthracite Coal	1.3 - 1.8	0.8 - 2.0
Garnet	1.5 - 1.8	0.2 - 0.6
Ilmenite	1.5 - 1.8	0.2 - 0.6

Source: Metcalf & Eddy (1979), USEPA (1974)

Media Density

Media density is the mass per unit grain volume. The density of the filter media affects the backwash flow requirements; for materials with the same diameter, those with higher density will require higher backwash rates to achieve fluidization.

The specific gravity of a material is defined as the ratio of the mass of the substance to the mass of an equal volume of water at a specified temperature. Specific gravity is used to calculate the density of a material. The specific gravity of filter media should be determined in accordance with ASTM Standard Test Method for Specific Gravity and Adsorption of Fine Aggregate. The test uses a displacement technique with a temperature for the test of 23^{0}C (73^{0}F) (and three alternative test methods are indicated; methods are for bulk specific gravity, bulk specific gravity (saturated surface dry) and apparent specific gravity. The bulk specific gravity (saturated surface dry) would most closely represent conditions that exist with granular media filtration, however, results are difficult to reproduce. Apparent specific gravity is more reproducible than the bulk specific gravity (saturated surface dry) for filter media and its use is generally accepted for the backwash fluidization calculations. Test results for specific gravity should be reported as the apparent specific gravity. Typical values are presented in Table III-2.

Media Shape

Grain shape is important because it affects the backwash flow requirements for the media, the fixed bed porosity, and the head loss during filtration. The measure of grain shape for granular media filtration is sphericity. It is defined as the ratio of the surface area of an equal volume sphere (diameter of d eq) to the surface of the grain. The sphericity of filter media can be determined by measuring the pressure drop through a sample and calculating the sphericity using the Carmen-Kozeny or Egun Equation for flow through porous media. This requires determining the equivalent spherical diameter and the porosity of the sample first, so that the only unknown is sphericity.

Materials which are more angular such as anthracite have lower sphericity. Typical values are presented in Table A-5.

Fixed Bed Porosity

The fixed bed porosity of a granular media filter is defined as the ratio of the void volume of the bed to the total bed volume and is expressed as a decimal fraction. Fixed bed porosity is affected by the sphericity of the media; those with lower sphericity will have a higher fixed bed porosity. Porosity is determined by placing a media sample of known mass and density in a fixed diameter, transparent cylinder. The depth of the sample in the cylinder times the cylinder area establishes the total bed volume. The media volume is calculated by dividing the mass of the sample by the density of the media. By subtracting the media volume from the total bed volume, the void volume is determined. The porosity is then calculated as the ratio of the void volume to the total bed volume of the sample.

Typical Media Properties and Design Standards

Some typically measured values of density, sphericity and porosity of different types of filter media are shown in TableIII-2. Differences in the densities of the various materials is what permits their use in dual media applications. Larger sizes of the lower density media, anthracite and granular activated carbon, are used as a cap material. These lower density media also have higher values of porosity which is desirable from a floc penetration standpoint. The larger media size and greater porosity will typically result in better deep bed filtration.

TABLE A-5
TYPICAL PROPERTIES OF FILTER MEDIA MATERIALS

Material	Density g/cm^3	Sphericity	Porosity
Silica Sand	2.6-2.65	0.7-0.8	0.42-0.47
Anthracite	1.45-1.73	0.46-0.60	0.56-0.60
GAC	1.3-1.5	0.75	0.50
Garnet	3.6-4.2	0.60	0.45-0.55

Silica sand is the most common filtration media. Sand filters have historically been used alone or in combination with other media. Silica sand is both economical and fine-grained, which results in a satisfactory quality of effluent. But, single media sand filters generally have short filter runs since the particles become trapped in the fine grains at the top of the medium, quickly increasing head loss to an unacceptable level. To overcome this, sands of varying sizes may be used in an unstratified bed. Alternatively, coarser materials have been used in combination with fine-grained sand, where the lighter, coarser materials will be found at the influent side of the bed. The most common coarse material used is anthracite coal. Garnet and ilmenite are generally used in multi-media filters as the third, or possibly fourth, polishing layer of filtration media.

Although granular activated carbon may be used as a filter media, usually its principal purpose is to remove dissolved organics. As a result, when granular activated carbon is used as a filter media, the carbon acts to filter particulate from the water and adsorb organic impurities in the water. The greatest disadvantage of granular activated carbon, especially with regard to hazardous and toxic applications, is that the media's adsorption capacity may be exhausted before its filtration capacity is exceeded. Granular activated carbon is more useful in domestic water treatment in removing organics exhibiting chlorine demand which reduces the need for chlorine addition. For hazardous and toxic waste sites activated carbon treatment should occur downstream of the filtration unit. The activated carbon unit's principal function should be to remove organic contaminants, not to filter particulate matter.

Manganese greensand is a natural zeolite (glauconite) treated with manganous sulphate and potassium permanganate, giving the media the characteristics of a catalyst. Manganese greensand removal is ion-specific, removing soluble iron and manganese by ion exchange, in addition to filtering out particulate material. Usually, a 1% to 4% solution of potassium permanganate ($KMnO4$) is fed upstream of the filters to oxidize the soluble iron and manganese to insoluble ferric and manganic precipitates. The majority of the oxides can be removed in the upper layers of the filter bed which is composed of conventional media (e.g., anthracite coal). Iron and manganese not removed in the upper layers will be filtered out by the bed of manganese greensand. The green sand can remove iron, manganese and potassium permanganate in insoluble and soluble forms. In this system, the manganese greensand acts not only as a physical filtration media, but as a catalyst in removing ions by chemical means. Solids can be removed by periodic backwashing. The oxidative capacity of the bed is restored by continuous regeneration with potassium permanganate. It is important to note that chemical feed rates should be proportional to influent rates. Excessive feed of potassium permanganate will result in a fully regenerated bed, leading to leakage of the potassium permanganate causing a pink tinge in the filter effluent. Generally, iron and manganese removal systems employ pressure filters. A typical manganese greensand filtration flow schematic is presented in Figure A-3. (Roberts Filter Manufacturing Company, US Filter Corporation/Permutit)

b. Filter Hydraulics

The flow of water through a clean bed granular medium filter has similar hydraulic characteristics as flow through underground stratum. Various empirical equations have been developed to compute the head loss due to the flow of water through filter media of uniform size in a clean state. Several of these equations are presented below.

Fair-Hatch:

$$\frac{h}{L} = \frac{k}{g} vu \frac{(1-\alpha)^2}{\alpha^3} \left(\frac{6}{Yd}\right)^2$$

Carmen-Kozeny:

$$h = \frac{f}{\phi} \frac{1-\alpha}{\alpha^3} \frac{L}{d} \frac{v^2}{g}$$

$$f = 150 \frac{1-\alpha}{N_r} + 1.75$$

$$N_r = \phi \frac{pvd}{\mu}$$

Rose:

$$h = \frac{1.067}{\phi} C_d \frac{1}{\alpha^4} \frac{L}{d} \frac{v^2}{g}$$

$$\textit{For } N_r \textit{ less than } 1\text{:}\ C_d = \frac{24}{N_r}$$

$$\textit{For } N_r = 1\text{-}10^4\ C_d \textit{ can be approximated by: } C_d = \frac{24}{N_r} + \frac{3}{\sqrt{N_r}} + 0.34$$

where:
p = density, kg/rn^3
h = head loss, m
f = friction factor
" = porosity
N = shape factor
L = depth, m
d = grain diameter, m
u = face or approach velocity, rn/s
g = gravity constant, 9.8 rn/s^2
C_d *= coefficient of drag*
k = coefficient of permeability (assumed 5 under most conditions of water filtration)
Y **=** *sphericity*
μ = dynamic viscosity, N•s/m2
v **=** *kinematic viscosity, m*^{2}*/s*
*Nr = Reynold*s number*

In a clean filter stratified by backwashing, the equations presented calculate the head loss as the sum of the losses in successive layers of the media. The head loss calculations are performed on the basis of a sieve analysis of the material and considering that the particles between adjacent sieve sizes are uniform. The modified equations for stratified media are as follows:

Fair-Hatch:

$$\frac{h}{L} = \frac{k}{g} vu \frac{(1-\alpha)^2}{\alpha^3} \left(\frac{6}{Yd}\right)^2$$

where: p_i *= the percentage of weight retained by sieve*
d_i *= the geometric mean size between adjacent sieves*

Carmen-Kozeny:

$$h = LK \Sigma \frac{f p_i}{d_i}$$

where: f = friction factor for each layer and

$$K = \frac{1}{\phi}\,\frac{1-\alpha}{\alpha}\,\frac{u^2}{g}$$

Rose:

$$h = \frac{1.067}{\phi}\,L\,\frac{1}{\alpha^4}\,\frac{u^2}{g}\,\Sigma\,\frac{C_d\,p_i}{d_i}$$

where: C_D = drag coefficient for each layer

The designer will typically provide a filter equipment/media supplier with information concerning the filter media size, layer depth and/or performance. The supplier will calculate and furnish information on the clean bed headloss to the designer. The equations discussed can be used to determine whether the information supplied by the manufacturer is accurate.

c. <u>Configuration</u>

Single media, dual media, multi-media filters and unstratified beds with either single or multi-media have been used in water filtration. A bed configuration should be chosen based on water stream, effluent quality, availability of materials, and backwash design. If necessary and practicable, pilot testing may be performed for selection of media type and configuration. Pilot testing will provide information on head loss and resultant effluent quality for each media considered. Pilot testing is addressed in Chapter I. If pilot testing is not performed, experience with similar water streams provide guidance in selecting media type and configuration. Backwash requirements should also be considered in making the final media selection.

Dual media filters employ two layers of media of different size and specific gravity. The flow will contact the lighter, coarser layer first (top size generally greater than 1-mm), with the finer layer used as a polishing step (reverse gradation) Dual media filters allow for maximum results in using two different media to effect both good effluent quality and deep bed penetration. Grading the media from coarse to fine allows greater penetration of solids within the bed and greater removal of solids by the coarse media due to the consequent increased available removal sites (increased "storage" capacity). Removal in the coarser media results in less head loss buildup. Dual media filters are the most common in practice. Unless extensive

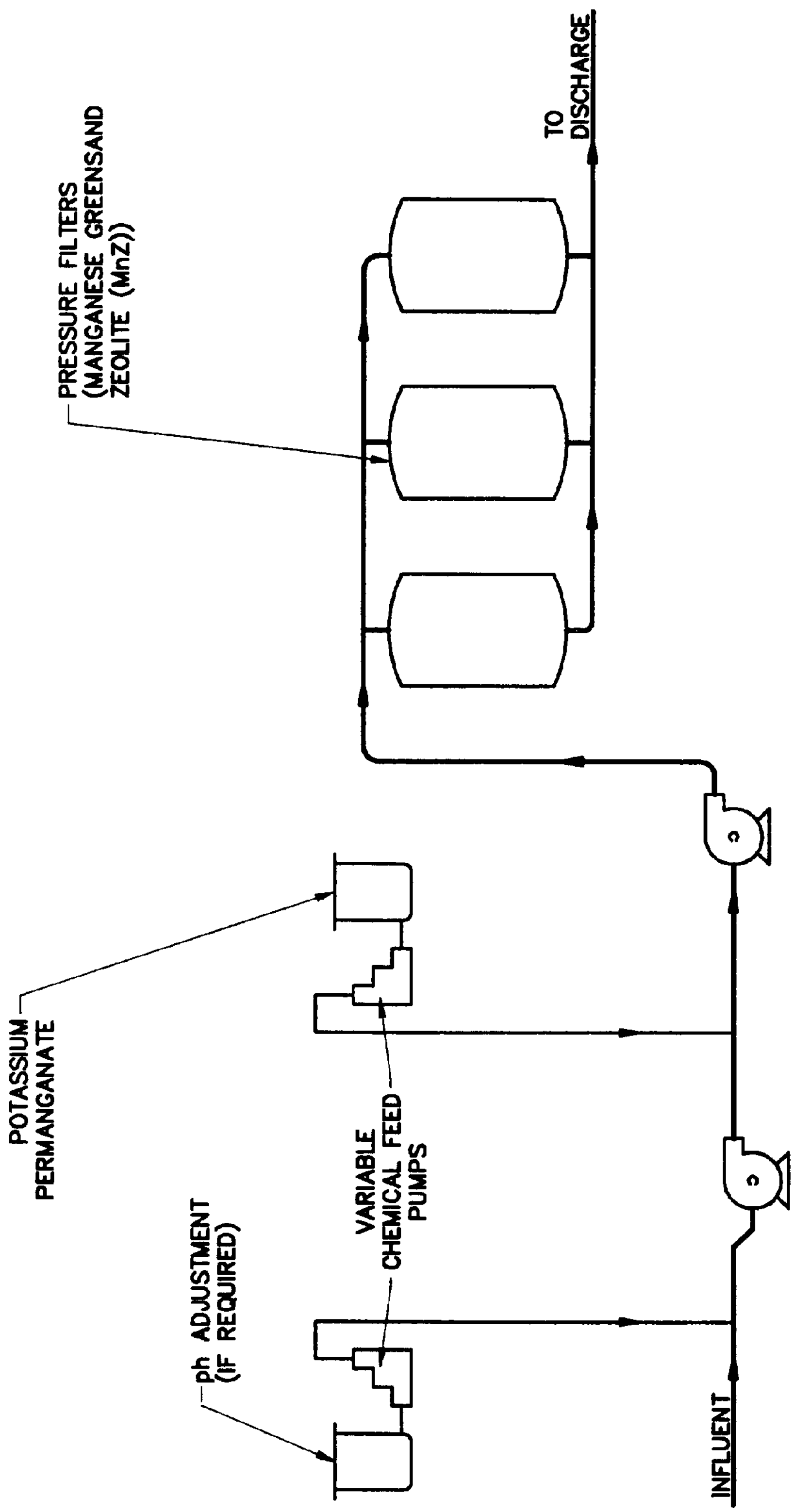


FIGURE A-2. TYPICAL FLOW DIAGRAM OF MANGANESE GREENSAND FILTRATION SYSTEM pilot testing is conducted, use of dual media is recommended for granular media filters, except continuous backwash systems.

The most common dual media filter configuration is crushed anthracite coal over silica sand. The larger anthracite provides bulk suspended solids removal; the sand provides removal of finer particles which were carried through the anthracite bed. Other types of dual media filters have been composed of activated carbon and sand, ion exchange resin beads and sand, and resin beads and anthracite.

Multimedia filters operate in the same manner as dual media filters, but have an additional layer of filtration media, offering a greater potential ability to tailor the filter design for the specific waste stream. A multimedia filter will be the most expensive to produce and install. Common multimedia beds are composed of anthracite, sand and garnet or ilmenite; activated carbon, anthracite and sand; weighted spherical resin beads, anthracite and sand; and activated carbon, sand and garnet or ilmenite.

One issue with dual media or multimedia configurations is the effect of intermixing of the media at the interface. The degree of intermixing will depend on the density, shape and size differences of the media at the interface. The media may be graded to maintain a sharp interface (coal size to sand size ratios at the interface of about 2:1) or substantial intermixing may be allowed (coal size to sand size of about 4:1). Better effluent quality generally results with at least a modest amount of intermixing, which is desirable in dual and multimedia filters. An intermixed bed more closely approximates the ideal coarse to fine filter bed, eliminating the impervious layer which may build up at a sharp interface. In practicality, some intermixing is unavoidable. No conclusive evidence is available to dictate or suggest the ideal or optimum degree of intermixing. One rule-of-thumb is that at least several inches of pure sand should be available past the zone of intermixing. Intermixing will result in faster head loss buildup due to increased suspended solids removal. (Cleasby, 1975; Weber, 1972).

Another important consideration in designing dual and multimedia filters is choosing media materials which will be compatible for backwashing. Improper combination of size and specific gravity can cause inadequate washing, intermixing of media after backwash, and loss of media during backwashing. One rule of thumb is that the coarser media be approximately two times the size of the finer media. Another suggestion is that the different media have the same terminal settling velocity. Figures A-3 and A-4, taken from Kawamura (1975), provide guidance in selecting the appropriate backwash rates based on media size.

For example, if anthracite coal with an effective size of 1.2 mm and uniformity coefficient of 1.5 was selected for bulk solids removal, the 60% weight particle size would be 1.8 mm. Figure III-2 indicates that the associated backwash rate (for anthracite with a specific gravity of 1.5) would be approximately 0.75 in/min (32 in/mm). Using this rate to choose the appropriate silica sand size results in choosing a 0.78 mm 60% weight particle size. Given the typical range of effective sizes and uniformity coefficient values for sand, a sand with a specific gravity of 2.60 and approximately a 0.52 mm effective size and 1.5 uniformity coefficient would satisfy this 0.78 mm result. Figure III-3 shows the effect of temperature on the backwash rate. This figures suggests that at temperatures ranging between 10°C to 40°C (50°F to 104°F), a 1.8 mm 60% weight particle size for anthracite coal should be used in combination with a range of sand sizes between approximately 0.75 to 0.85 mm 60% weight particle size for fluidization at similar backwash rates.

3. Media Support and Underdrain Systems

With the exception of upflow and downflow continuous backwash systems, granular filtration media are supported by an underdrain system. In addition to providing this support, the underdrain system acts to distribute the backwash water evenly, collect the filtered water and prevent loss of the filter media with the filtered water. For conventional systems, a layer of gravel is often placed between the media and the underdrain system to aid in preventing media loss. The principal consideration in underd-rain design is the uniform distribution of backwash water. Some common underdrain systems include pipe laterals with orifices or nozzles; ceramic or plastic block laterals with holes, nozzles or porous plates; lateral T-Pees; plenum, precast or monolithic concrete, with holes, nozzles or porcelain spheres (Wheeler-type); plenum with porous plates; and porous plates in ceramic block laterals. Table III-3, taken from Monk, compares some conventional underdrain systems.

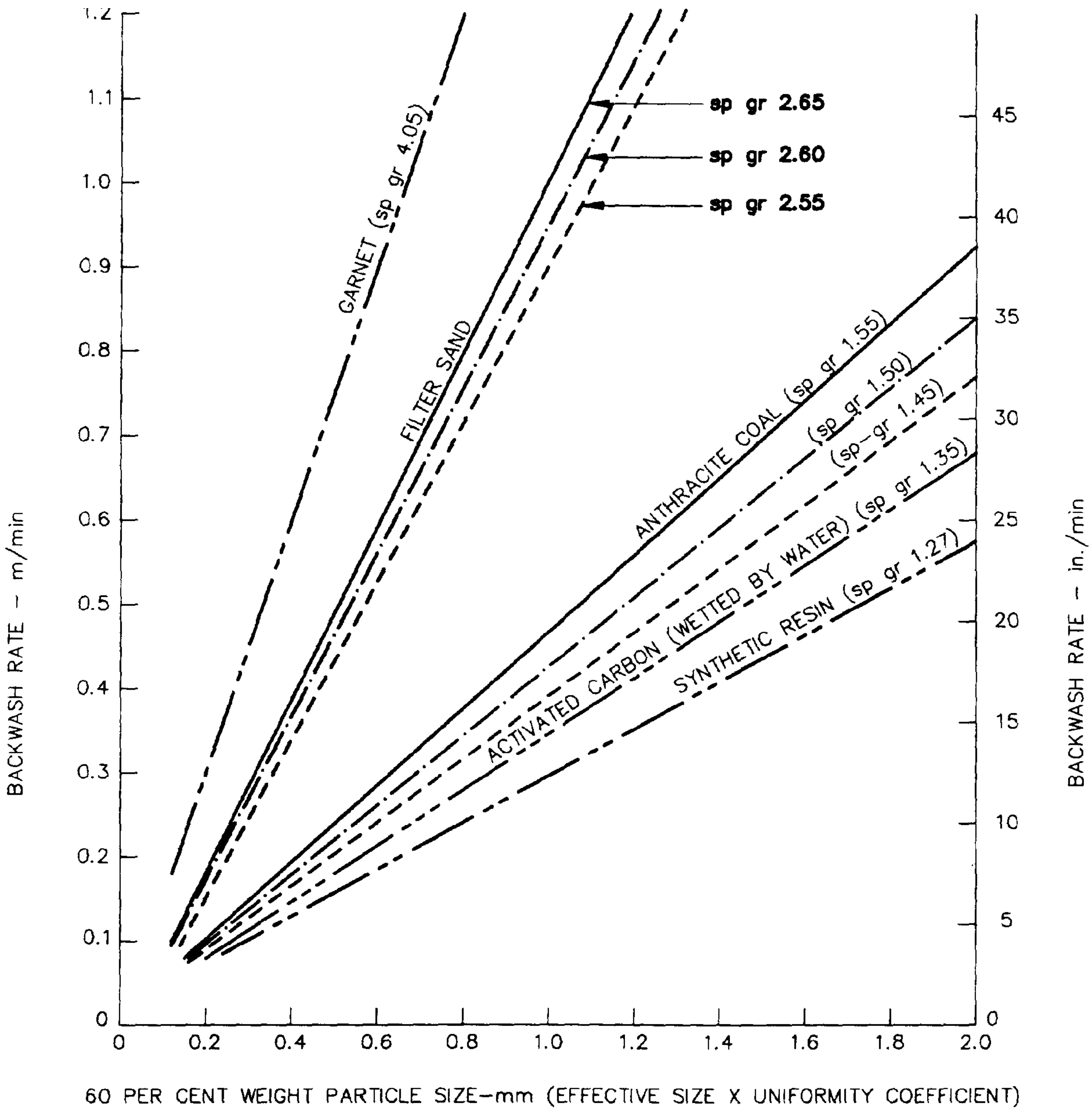
TABLE A-6
COMPARISON OF UNDERDRAIN SYSTEMS

TYPE	ADVANTAGES	DISADVANTAGES
Pipe laterals with noz-zles	Air-scour can be used Less gravel layers needed Shallower filter box required	Nozzles result in greater head loss Cannot use concurrent air and water

Pipe lateral with orifices	Relatively inexpensive material costs Simple to construct and install	Multiple gravel layers needed Integral air-scour cannot be used Gravel layers increase depth of filter box
Precast concrete T-Pees	Very little head loss Can be used to form plenum	Multiple gravel layers needed Integral air-scour cannot be used Casting and laying is labor intensive Gravel layers increase depth of filter box
Ceramic tile block	Good backwash distribution Small head loss Relatively easy to install	Integral air-scour cannot be used Requires up to seven layers of gravel Blocks difficult to handle Deeper filter box because of gravel and depth of block
Plastic dual lateral block	Light to handle Small head loss Water and air can be used concurrently Good water-to-air distribution	Requires up to seven layers of gravel Deeper filter box because of gravel and depth of block Limited flexibility in range of air-scour rates Blocks require care in laying correctly
Plenum with precast concrete block and nozzles	With appropriate nozzles air-scour can be used Good water-to-air distribution Gravel layer not needed	Difficult to construct Deeper box because of plenum Extra care is needed to avoid nozzle clogging
Wheeler-type System	Low head loss Good water distribution	Multiple gravel layers required Integral air-scour cannot be used Costly construction requirement Deeper filter box because of plenum and and gravel layers
Plenum with monolithic floor and nozzles	Water and air can be used concurrently Little or no gravel required Nozzles available that can be adjusted to ensure uniform air distribution Air-scour rates can be varied	Deeper box because of plenum Extra care is needed to avoid nozzle clogging Nozzle type must be carefully specified
Plenum with precast concrete blocks and nozzles	Water and air can be used concurrently Little or no gravel required	Deeper filter box because of plenum Less reliable than a monolithic floor Extra care is needed to avoid nozzle clogging
Plenum with porous plates	Excellent water distribution No gravel layers needed	Integral air-scour cannot be used Filter box is deeper because of plenum History of damaged plates Little, if any, competitive market Usually not recommended for wastewater filtration

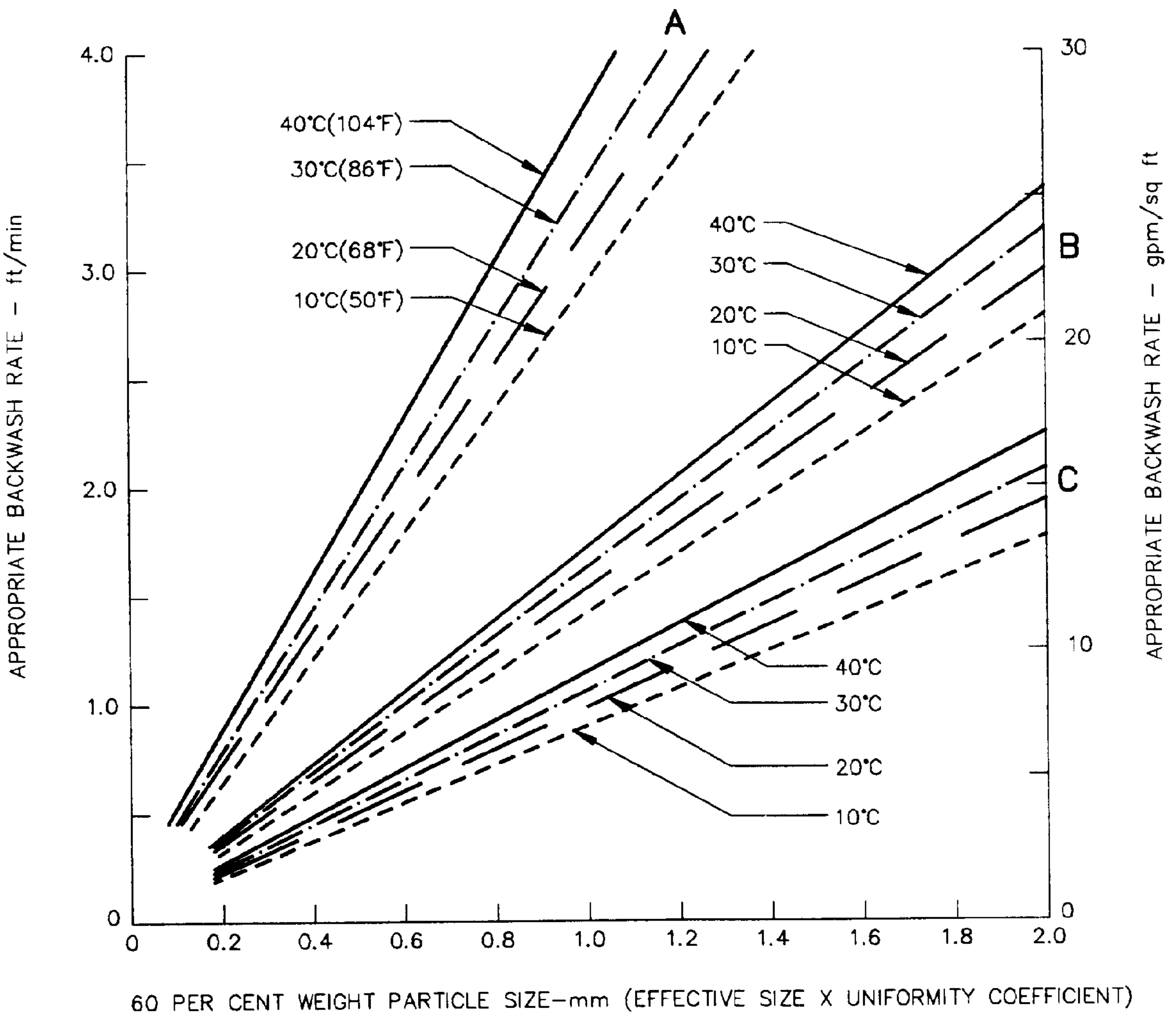
Source: Monk (1987)

Figure A-5 depicts some commercially available underdrains.



SOURCE: KAWAMURA (1975)

FIGURE A-3. APPROPRIATE FILTER BACKWASH RATE AT WATER TEMPERATURE 20°C (68°F).



A – FILTER SAND (sg=2.60)

B – ANTHRACITE COAL (sg=1.50)

C – SPHERICAL RESIN GRAINS (sg=1.27)

SOURCE: KAWAMURA (1975)

FIGURE A-4. APPROPRIATE FILTER BACKWASH RATE FOR FILTER MEDIA

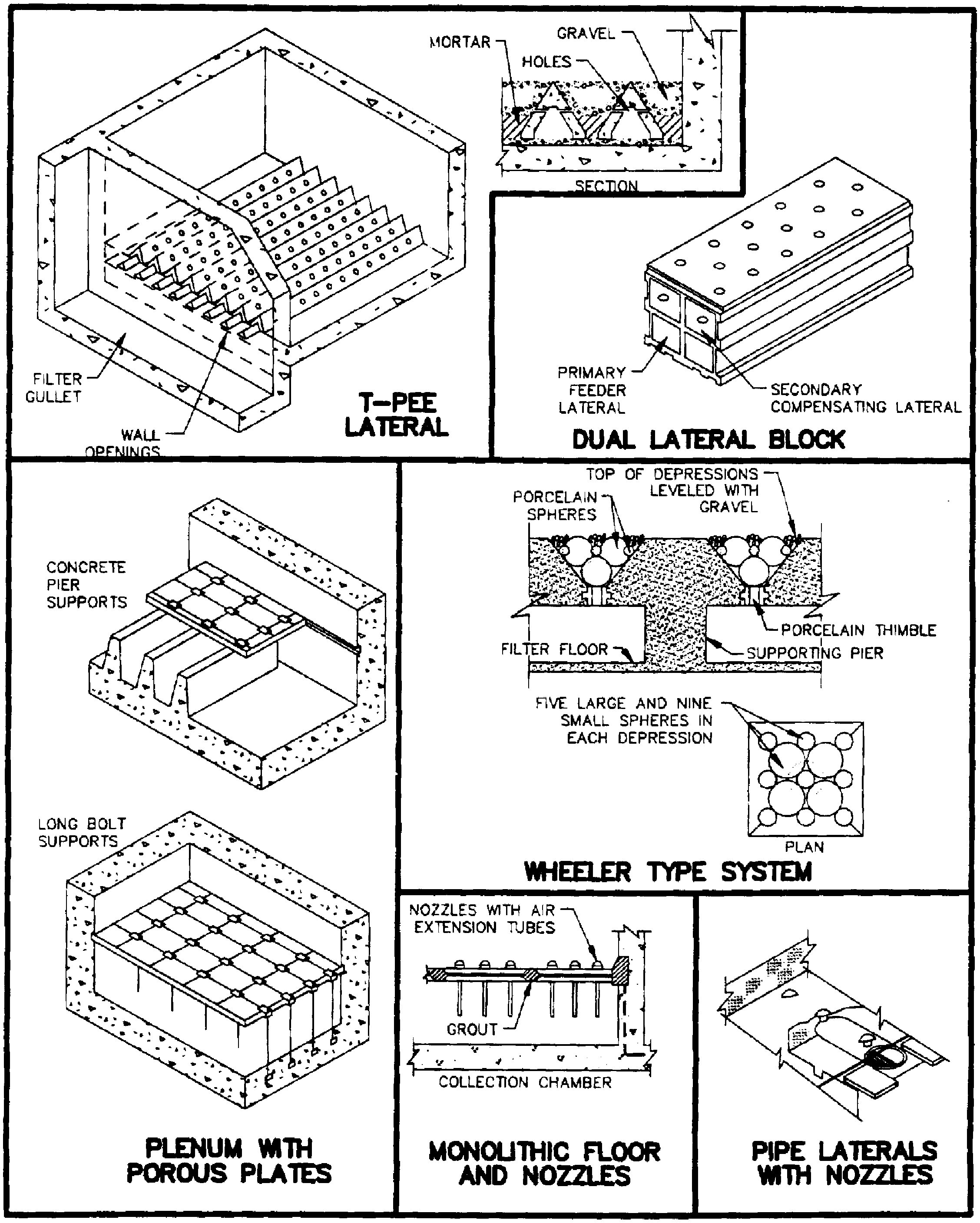


FIGURE A-5. UNDERDRAINS

Considerations in selecting an underdrain system include the size of the underdrain, depth of the gravel layer, head loss during backwash, and material of construction. The size of the underdrain will affect the depth of the filter box. The gravel layer depth depends on the orifice size and spacing. Orifice size will greatly affect head loss during backwash. The underdrain should be constructed of a material which will be resistant to any contaminants in the water to be filtered. Some additional considerations are discussed below.

- Porous plates have closely spaced small holes completely covering the filter box floor. Medium is placed directly on the plates. The small holes considerably increase the frictional head loss through the filter and are more susceptible to clogging due to chemical precipitation or encrustation across the holes.

- If the designer determines air scour is required, some underdrain systems will be eliminated from consideration. Table 111-3 provides the required information.

- The overall depth of the system must be considered when selecting the underdrain since this will, in part, dictate the size of the filter box.

- Nozzles are available with a wide size range (0.25 to 9.0 mm) for slots, so that the underdrain can be matched to the media size. Matching the media and slot size will eliminate the need for gravel, reducing required filter box height.

- Pipe laterals with orifices or nozzles are rarely used anymore.

- Materials of construction must be made corrosive-resistant to the water to be filtered.

- Concrete filters are not generally used in installation sized for typical hazardous and toxic waste applications (less than 15 L/s (200 gpm)).

- Package systems used for low-flow (less than 15 L/s (200 gpm)) applications will generally have standard underdrains designed for the system. The manufacturers will provide guidance on whether the particular application requires a differing underdrain system.

4. Number of Units

The number of filtration units must be sufficient to assure that the backwash flowrates do not become excessively large and that when one filter unit is taken out of service for backwashing, routine maintenance or repairs, the loading on the remaining units is within acceptable design criteria. The number of units should be kept at a minimum to reduce the cost of piping and construction. After peak filtration and plant flow rates are established, the number of units should be determined based on total required surface area and space and cost considerations. Where multiple units are specified, the number of units should be based on one unit being out of service at all times. Usually, the minimum number of units is two, with four often recommended. But, for typical low flow HTRW applications (<15 L/s (200 gpm)) and with continuous backwash systems, one unit may be sufficient if it is acceptable to interrupt filtration (e.g., shut off recovery wells or increase equalization storage) for backwash and/or maintenance.

A suggested rule-of-thumb for determining the number of filter units is:

$$N = 2.7\sqrt{Q}$$

where: N number of *filter units*
Q = design capacity in mgd

5. Filter Size

Generally the surface area required is based on the peak filtration and peak flowrate. Bed depth, filtration rate, head loss and filter run length also help determine the required filter size. Capital and operating costs must also be considered in designing the filter.

The filter box must be large enough to house the media, underdrain, any control mechanism and troughs. Additionally, the filter box size will be, in part, determined by the backwash requirements (expansion of the bed occurring during backwash) and control system.

6. Valves and Piping

The necessary valves and piping are for influent flow control, effluent flow control, and the backwash cycle. Additionally, wash-water troughs must be designed.

Valves are used to control flow. Valves are selected based on desired service. Some function (1) only when fully closed or fully open; (2) by throttling, to reduce the pressure and flow rate of the water; or (3) to permit flow only in one direction or under certain conditions of temperature and pressure. Valves basically function by placing an obstruction in the path of the water, providing resistance to flow. Some basic valves are briefly described below.

- Gate Valves - Gate valves are used to minimize pressure drop in the open position and to stop the flow of fluid rather than to regulate it

- Globe Valves - Globe valves are used for controlling flow. The flow passes through a restricted opening. Associated pressure drop is large.

- Butterfly Valves - Butterfly valves operate by rotating a disk from a parallel position to one perpendicular to the fluid flow.

- Ball Valves - Ball valves use a spherical sealing element. The valves may be used for throttling. Pressure drop is low.

- Check Valves - Check valves permit flow in one direction only. When the flow stops or tends to reverse, the valve automatically closes by gravity or by a spring pressing against a disk.

More information on these and additional valves is available in Perrv's Chemical Engineers' Handbook and vendor literature.

Piping is specified in terms of its diameter and wall thickness. The optimum size of pipe for a specific situation depends upon the relative cost of investment, power, maintenance and stocking pipe and fittings. Low velocities should ordinarily be favored, especially in gravity flow from overhead tanks. The facilities layout should minimize piping requirements.

Backwash troughs collect the backwash water and transport it to the disposal facilities. The troughs must be correctly located to each other and relative to the media. Backwash gutters should be as close to the media as possible to minimize the amount of dirty water left after backwashing and to minimize the height of the filter box, but should be high enough to prevent loss of media. The gutter must be large enough to carry all the water delivered to it. French (1981) has given a dimensionless relationship to help determine correct trough spacing:

$$H = 0.34S$$

where

H = height of the top edge of the trough above the fluidized bed

S = center-to-center spacing of the troughs

Two or more troughs are usually provided. The clear horizontal distance between troughs should not exceed 1.5 to 2 meters (5 to 6 feet), and the top of the troughs should not be more than 750 mm (30 inches) above the top of the bed. (TM 5-813-3)

Common materials used for backwash gutters include concrete, steel, aluminum and fiberglass. Materials of construction should be chosen based upon compatibility with the water to be filtered.

7. <u>Backwash</u>

a. <u>Process Description</u>

A necessary component for long-term operating success of granular media filters is adequate bed cleaning. Traditionally this has been accomplished using an upflow water wash with full-bed fluidization. Backwash water is introduced into the bottom of the filter bed through the underdrain system. The filter media gradually assumes a fluidized state as backwash flow is increased. Recently, surface washing and/or air scour has been used to supplement water backwash. Surface wash systems consist of orifices located 50 to 80 mm above the fixed-bed surface that inject water over the bed prior to and during water backwash. Air scour supplies air to the full filter area from orifices located under the filter medium. Air scour may be used either prior to the water backwash or simultaneously with the water backwash. These processes are discussed in Section III.B.4.b.

Proprietary systems have been developed in which media cleaning is performed continuously. This is accomplished in the deep bed continuous backwash filter by removing media from the filtration zone for cleaning; and returning the media once cleaned. These systems are addressed in Section III.C., below.

b. <u>Disposal Options</u>

Disposal of backwash water is usually accomplished by re-filtering, settling in an upstream clarification unit, or dewatering to concentrate the solids.

Generally it is advisable to provide either treatment (e.g., clarification and/or dewatering) or storage prior to re-filtering the backwash stream. Storage is more typically used, except for continuous backwash systems. The water can be stored and delivered at a uniform rate to the influent flow. A storage tank is usually necessary to avoid sending a high solids or high volume "slug" through the filter at once. To dewater, the waste stream is typically collected, conditioned and settled. If dewatering is used, the wet stream from the dewatering unit is often returned to the process steam ahead of the filtration unit. If a separate treatment train is not desirable, or the process train configuration lends itself to simple re-treatment, the waste stream may be returned to upstream settling/clarification units for solids separation. The designer should always consider the hydraulic effects on upstream unit processes when the backwash waste is returned directly to the treatment train. Alternatively the backwash water may be disposed of off-site.

The disposal of both the backwash water, and eventually the media, is a significant design consideration when designing for hazardous and toxic waste applications. The designer is referred to the Resource Conservation and Recovery Act (RCRA) and the Clean Water Act regulations and other applicable federal, state and local regulations to determine the required treatment or permitting prior to release. The designer should try to minimize all waste streams which are subject to regulation and treatment as a hazardous waste.

B. Gravity and Pressure Filtration

1. Description of Unit

Gravity filters are granular filters which are open to the atmosphere. Removal of suspended solids is accomplished as the influent passes through the porous, granular media. The removal occurs within the interstices of the filter medium by interception, impaction and straining. The hydrostatic pressure over the bed provides the driving force to overcome head loss through the unit. Maximum head loss typically is less than 2.5 to 3 meters (8 to 10 feet), and is dependant upon the hydraulic profile of the treatment system. Backwash is initiated at this limiting head loss. The direction of water flow may be downflow, upflow, or biflow. The downflow designs are most common. If an upflow configuration is used, a retaining grid must be placed above the media bed to help prevent loss of media in the effluent. This prohibits high filtration rates in upflow filters. Biflow configurations, where influent is introduced to the bottom and top of the bed with the effluent withdrawn from a strainer placed within the bed, have been used principally in Europe. Backwash is always upflow, regardless of the operating flow direction. Backwash may consist of water wash in conjunction with surface wash and/or air scour. Flow rate may be controlled using either constant-rate filtration or declining-rate filtration. These controls will be discussed in Paragraph VIII. Figures A-6 and A-7 depict a typical gravity filter layout.

Pressure filtration systems operate in essentially the same manner as gravity filtration systems, except that pressurized conditions, achieved by pumping, supply the required driving force. Pressure filters may be operated with terminal head losses up to 10 meters (30 feet) (Water Environment Federation, 1992). A typical pressure filter is shown in Figure A-8. Again, downflow, upflow and biflow configurations are available. In addition to control by constant-rate filtration and variable-declining-rate filtration, pressure filtration can also be operated at constant-pressure (also discussed in Paragraph VIII). Pressure filtration units are usually constructed of cylindrical steel shells with either horizontal or vertical axes. Backwash is performed in substantially the same manner as for gravity filters.

2. Media Configuration

Single medium stratified filter beds are not typically used for wastewater treatment except in continuous backwash filters. However, for HTRW and industrial applications single media stratified beds may be considered. For typical gravity and pressure filtration systems, single medium filter beds will become stratified with finer grains on top after backwash. This results in unfavorable head loss buildup resulting from surface straining of the solids within the finest medium layer. Instead, if a single medium is to be used, the bed should be unstratified. Two types of unstratified single medium beds have been used. One type uses a single, uniform, coarse medium (approximately 1 - 3 mm in diameter) in a deep filter (approximately 2 meters or 6.5 feet). Effluent quality may suffer somewhat with use of this type of bed since fine particles may not be entrapped by the coarse media. Additionally, prohibitively high backwash rates may be required to fully fluidize the bed. For example, the minimum backwash velocity needed to fluidize 2-mm diameter sand grains is approximately 1800 L/(min m^2) (45 gal/mm/sq ft) as opposed to a more typical required backwash velocity of 600 L/(min m^2) (15 gal/mm/sq ft) (Dahab, 1977). The second type of unstratified single media bed uses a single medium of varying sizes to a depth of approximately 1 meter (3 feet) used with a combined air-water backwash. Use of this type of unstratified

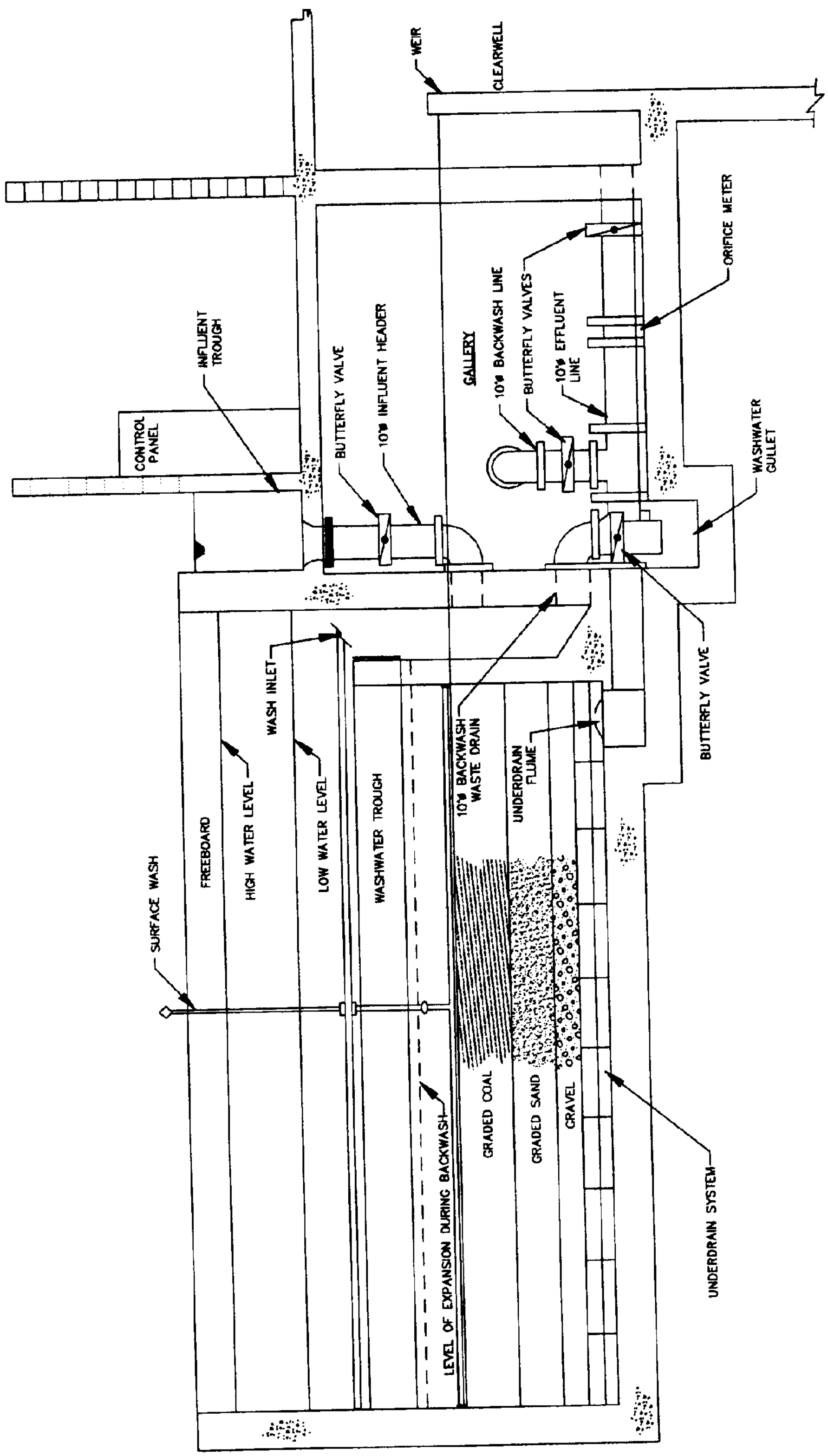


FIGURE A-6. GRAVITY FILTER - SECTION

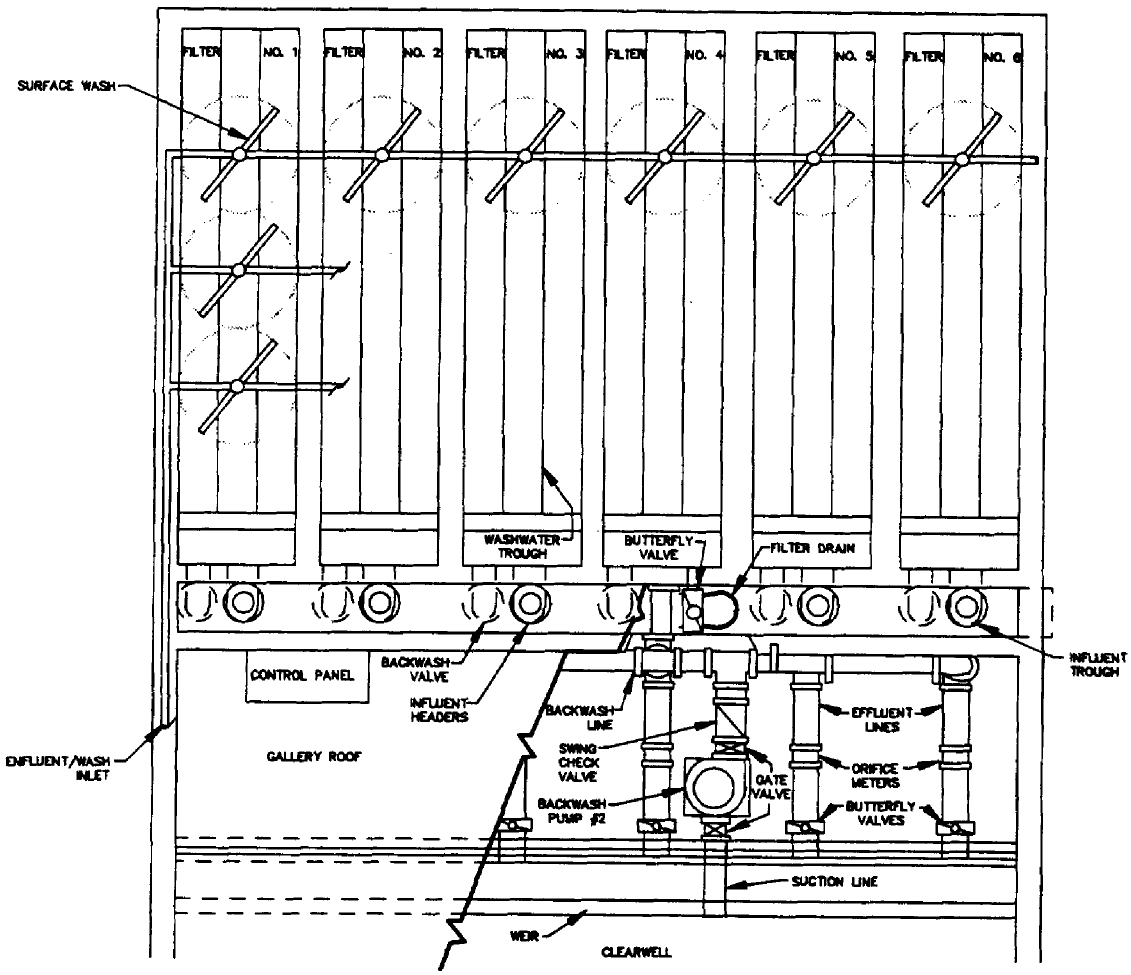


FIGURE A-7. GRAVITY FILTER - PLAN

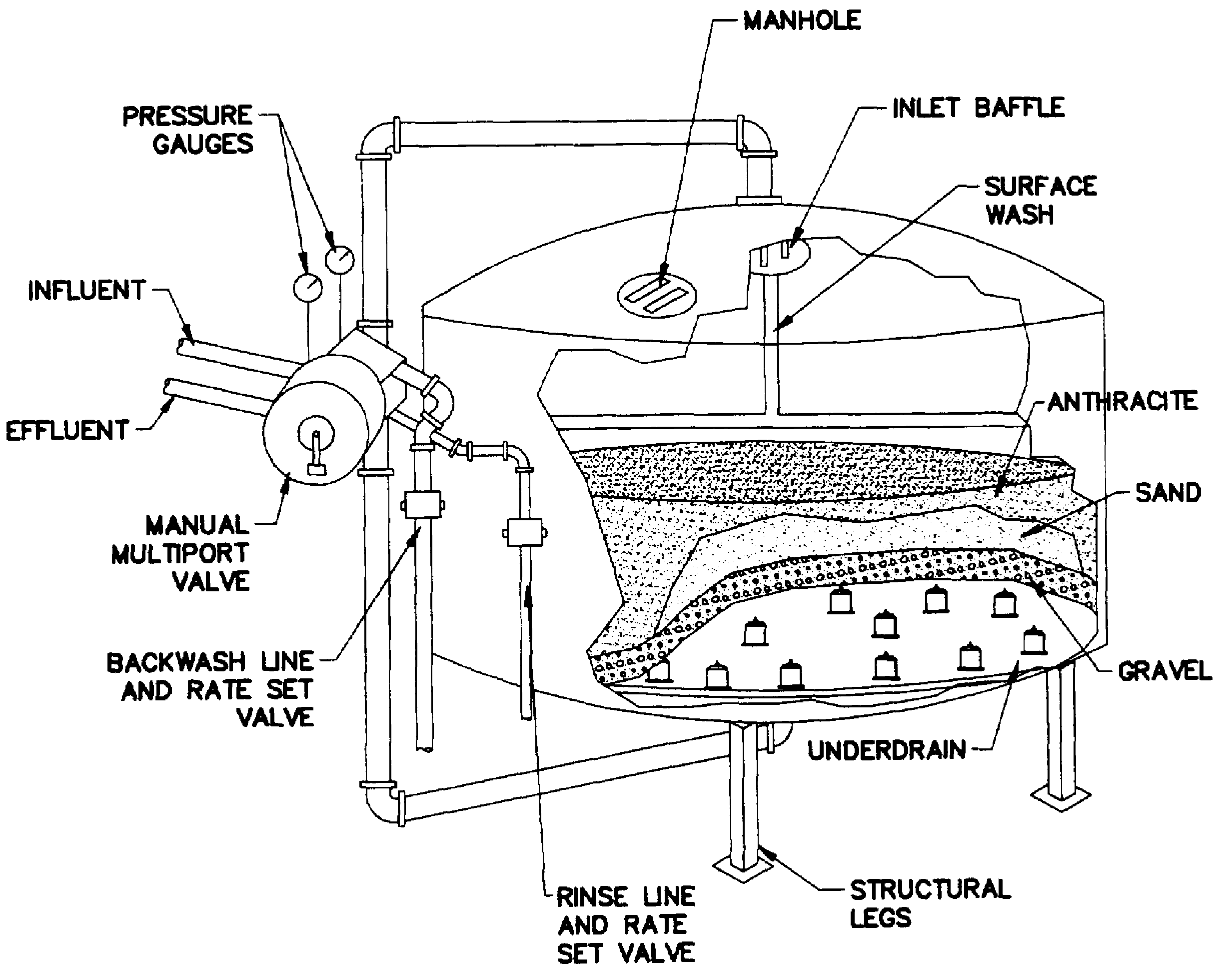


FIGURE A-8. PRESSURE FILTER

bed results in uniform average pore size throughout the filter bed. Therefore, in-depth filtration is more likely to occur, which results in longer filter runs. Use of air-water backwash eliminates the need for fluidization and consequent stratification of the media. This type of filter has been most commonly used in potable water treatment. Generally, it is advisable to use dual media filters.

Table A-7 and A-8 present typical media designs for filters. Additional information is presented in TM 5-814-3, "Domestic Wastewater Treatment" and TM 5-813-3, "Water Supply, Water Treatment."

TABLE A-7
TYPICAL MEDIA DESIGNS

CHARACTERISTICS	VALUES	
	RANGE	TYPICAL
Dual Media		
Anthracite Depth, mm Effective Size, mm Uniformity Coefficient	300 - 600 0.8 - 2.0 1.3 - 1.8	450 1.2 1.6
Sand Depth, mm Effective Size, mm Uniformity Coefficient	150 -300 0.4 - 0.8 1.2 - 1.6	300 0.55 1.5
Tri-Media		
Anthracite Depth, mm Effective Size, mm Uniformity Coefficient	200 - 500 1.0 - 2.0 1.4 - 1.8	400 1.4 1.6
Sand Depth, mm Effective Size, mm Uniformity Coefficient	200 - 400 0.4 - 0.8 1.3 - 1.8	250 0.5 1.6
Garnet or ilmenite Depth, mm Effective Size, mm Uniformity Coefficient	50 - 150 0.2 - 0.6 1.5 - 1.8	100 0.3 1.6

Source: WEF/ASCE, 1991

TABLE A-8
TYPICAL MEDIA DESIGNS

Media Design	Anthracite Coal			Silica Sand			Garnet			Typical Application Conditions
	Effective Size (mm)	Depth (mm)	Uniformity Coefficient	Effective Size (mm)	Depth (mm)	Uniformity Coefficient	Effective Size (mm)	Depth (mm)	Uniformity Coefficient	
Single	-	-	-	1 - 2	1525	1.2	-	-	-	A
Single	-	-	-	2 - 3	1830	1.11	-	-	-	A
Dual	0.9	915	<1.6	0.35	305	<1.85	-	-	-	B
Dual	1.84	380	<1.1	0.55	380	<1.1	-	-	-	A
Tri	1.0 - 1.1	430	1.6 - 1.8	0.42 - 0.48	230	1.3 - 1.5	0.21 - 0.23	100	1.5 - 1.8	B
Tri	1.2 - 1.3	760	-	0.8 - 0.9	305	-	0.4 - 0.8	150	-	C

Note: A = Heavy Loading, Strong Floc
B = Moderate Loading, Weaker Floc
C = Moderate Loading, Strong Floc

Source: USEPA, 1975

3. <u>Design Considerations</u>

Typical filtration rates for granular filters are 40 to 100 L/(min m^2) (1 to 2.5 gpm/ft^2) for rapid filters and 100 to 600 L/(min m^2) (3 to 15 gpm/ft^2) for high rate filters. Higher filtration rates are generally preferred to decrease the capital cost of the filter (less filter area required) and the higher filtration rates result in greater penetration of solids into the bed. The trade-off is potentially poorer effluent quality. When designing a filter for a specific net production (m/hr (gpm/sq ft)), downtime for backwash and time associated with treatment of the backwash water, if applicable, must be taken into consideration. Head losses of approximately 3 meters (10 feet) permit a reasonably long run in gravity filters. Lower head losses (2 meters (6.5 feet)) may be acceptable for dual media configurations. The loss of head through the filter is determined by summing the incremental losses through the underdrain (and supporting gravel, if applicable), media, static height, and valves and piping.

For concrete gravity filters, filter boxes are usually arranged in rows along one or two sides of a common pipe gallery, minimizing piping required for influent, effluent, wash water supply and wash water drainage. Gravity filters may be of concrete or steel shell construction. Concrete units are usually rectangular and steel units are spherical. Generally, the steel units are made for smaller influent flows than the concrete units and may be more practical for HTRW applications.

Pressure filters shells must withstand high operating pressures and, therefore, must be manufactured in strict accordance with the American Society of Mechanical Engineers (ASME) standards for pressure vessels. Pressure filter units are sized to use commercially available shells. The shells can be mounted either vertically or horizontally. The vessel will house the media; media support structures; distribution and collection devices for influent, effluent, backwash water and waste; supplemental cleaning devices and necessary controls. Media support structure are typically pipe laterals with nozzles or orifices or a plenum with porous plate-type structure using a framework similar to a well screen. Allowable head losses approach 10 meters (30 feet) (Water Environment Federation, 1992). With pressure filtration, only single pumping typically is required. The water may be pumped from wells, for example, through the filters and to further waste treatment or storage facilities.

4. Backwash Alternatives

a. Process Description

Granular media filters are cleaned by reversal of the flow through the bed based on a triggering measurement such as effluent quality or head loss or after a predetermined time period. During backwashing, the media are usually fluidized to allow the captured particulate to be released into the water and collected in washwater troughs. The washing process may be supplemented by air injection, surface wash or jets of water. Auxiliary cleaning is recommended, particularly when filtering wastewaters. Surface wash and surface air scour are used to loosen and remove deposits from upper levels of the medium. Air scour may also be used to reduce washwater requirements and clean the deeper portion of the filter bed.

Factors governing backwash system design include size distribution, depth, shape and specific gravity of media, density of bed, influent solids characteristics, pretreatment, any supplemental cleaning by surface wash or air scour, and disposal of backwash waste.

b. Process Alternatives

Water backwash uses the shearing action of the water to dislodge the accumulated material on the media. The dislodged material is flushed through the bed and wasted through the washwater gutters. Traditionally, the media has been fluidized or expanded to assist in the shearing and removal of solids. Experience has indicated water wash alone is insufficient to adequately clean the filter bed, especially when filtering waste water.

Surface wash is used to provide additional shearing force. The surface wash system produces high velocity water jets 50 to 80 mm (2 to 3 inches) above the unexpanded media. The jets are introduced by orifices located on a fixed piping grid or on a rotating arm. Surface wash water rates are generally from 40 to 120 L/(min m^2) (1 to 3 gpm/ft^2) at 3.5×10^5 to 7 x 10 Pa (50 to 100 psi). The cycle is started 1 to 3 minutes before water backwash, is operated for a period of time (5 to 10 minutes) simultaneous with water backwash and is then shut off. The orifices will become submerged during the water backwash. The surface wash should be shut of f at least one minute prior to the end of the backwash cycle. This is particularly important with dual media and multimedia beds, where the horizontal currents must be dissipated before the media settles and re-stratifies.

The diameter of a sweep washer should be selected so that approximately 80 mm (3 inch) clearance is available at the nearest wall. If the filter is constructed in a rectangular shape, it may be advisable to use multiple surface washers to cover the area adequately. The washers should be located such that they remain parallel to the media surface. Sufficient clearance must exist beneath the wash troughs to allow for rotation as well as 50-80 mm (2-3 inches) between the washer arm centerline and the media surface.

Auxiliary agitation may also be achieved by air scour. Air is introduced at the bottom of the filter medium prior to water backwash at approximately 1 to 1.5 $m^3/(min\text{-}m^2)$ (3 to 5 cfm/ft^2) for 3 to 10 minutes. Water backwash is then initiated, and air scour may continue until the water is about 250 mm (10 inches) from the wash water trough. Air may be introduced either above the gravel layer or through the orifices of the underdrain. For design purposes, it should be assumed that there is no reduction in a backwash rate when air scour is utilized.

5. <u>Backwash Control</u>

a. <u>Rates/Times</u>

Backwash must be performed at a rate sufficient to fluidize the entire bed and for a time sufficient to wash the dislodged particles out of the bed and into the wash water gutter. For combined water-air backwash, fluidization is not necessary (although some bed expansion will occur). The backwash rate should be adjusted at the end of the cleaning cycle to ensure reclassification of the filter media. Quick shutdown may result in increased packing and consequent smaller porosity and less pore space for filtration. For operation on hazardous and toxic waste sites, the designer must keep in mind that the turbulence during backwash may release volatile emissions. Potential design solutions for this problem may include enclosing the vessel and scrubbing off-gases or using an upstream unit operation to remove volatile constituents prior to the filtration process.

Maximum backwash rates are typically between 600 and 1000 $L/(min\ m^2)$ (15 and 25 gpm/ft^2) and the filter is normally backwashed for a period of 8 to 10 minutes. The required back-wash rate for a given filter is dependant on the filter media particle size and density, and the backwash water temperature.

More detailed information regarding the calculation of the required backwash rate is presented in Section S.C., below.

b. Source/Storage

The source of the backwash water can either be filtered water (effluent stream) or water from an off-site source; i.e, potable water supply. The backwash water generally should be stored in a wash water tank to provide adequate capacity for backwashing when not available directly from an off-site backwash water supply. The volume of the tank will be determined by filter size, rate and time of backwash, and frequency of backwash. The water may be supplied for backwashing by using an elevated tank or a wash water pump. Typical required storage capacity is 6 cubic meters per square meter of filter area (150 gallons per square foot). The daily backwash volume is normally in the range of 1% to 4% of the daily treatment rate, but during peak conditions, 10% or more can be reached.

c. Pressure Loss and Fluidizing Velocity

Pressure loss during backwash includes loss through the underdrain orifices or plates, loss through the expanded filter bed, loss through the gravel layer, friction and minor losses in underdrain channels and piping from source of backwash supply, and elevation differences to the top edge of the wash water trough. The most significant pressure loss is usually that through the underdrain. Head losses through the underdrain system are obtained from the manufacturer. Loss through the gravel layer may be estimated by treating the gravel layer as porous media. Loss through valves and piping may be calculated using standard fluid flow equations.

Backwash fluidization in a granular media filter bed can be described as the upward flow of water through the media with sufficient velocity to suspend the grains in the water. As the rate of backwashing is increased the head loss through the media is linear until the rate is reached where the head loss is equal to the weight of the media grains in water. At this point, no further increase in head loss will occur. As the flow rate is increased further, the media expands and provides a larger flow area that can accommodate the higher flow without additional head loss. A typical curve for fluidization of a granular media is shown in Figure A-9. The point of the curve labeled V_{mf} is referred to as the point of incipient fluidization, or more simply, the minimum fluidization velocity. It is the superficial velocity required for the onset of fluidization and can be determined by the intersection of the fixed bed and fluidized bed

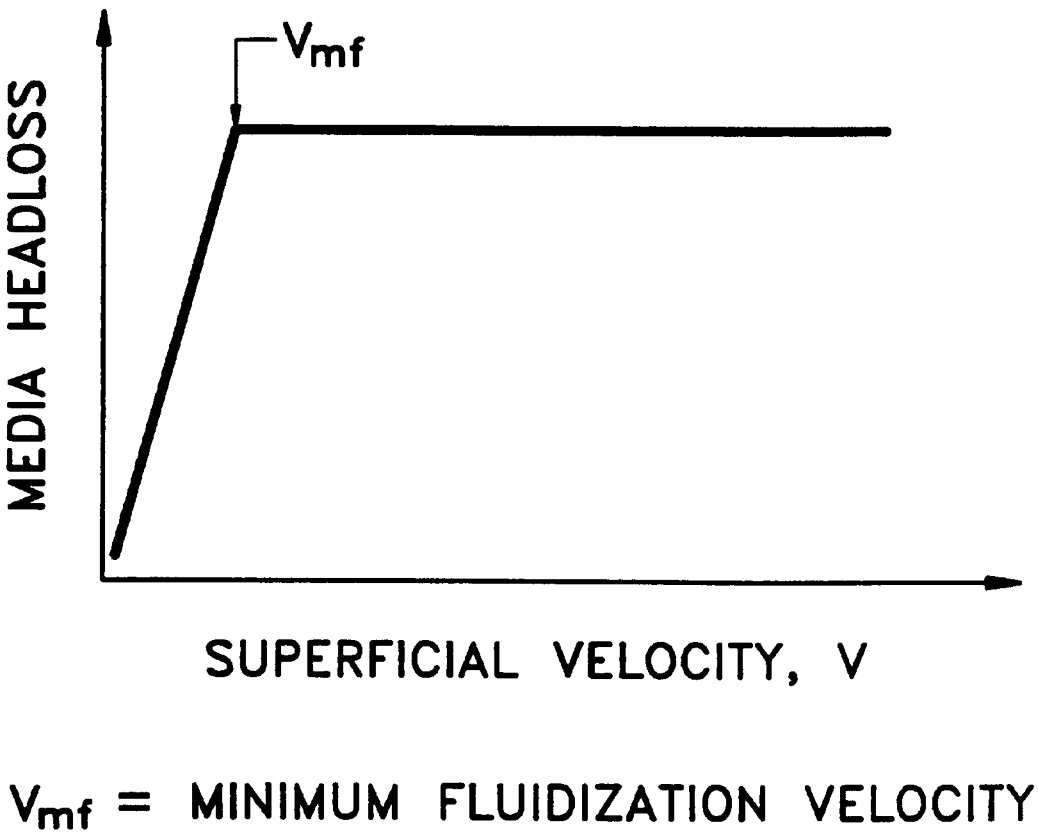


FIGURE A-9. HEADLOSS VERSUS SUPERFICIAL VELOCITY head loss curves.

The pressure drop at the point of fluidization can be calculated from the following equation:

$$h = L\,(SG_m - 1)\,(1 - ,)$$

where:

h = head loss in feet of water pressure
L = bed depth in feet
, = porosity of expanded bed
SG_m = specific gravity of the media

The minimum fluidizing velocity required for a media can be calculated using an empirical equation developed by Wen and Yu as presented below. The equation shows that the required fluidizing velocity is affected by the media particle size, the particle density and the water temperature. In the filter bed, there is a range of grain sizes as determined from the sieve analysis of the media. The particles do not all fluidize at the same superficial velocity; smaller particles fluidize at a lower velocity than the larger particles. Therefore, to assure complete bed fluidization, it is necessary to check the fluidizing velocity of the coarser grains. The d_{90} size, that is, the particle size corresponding to the sieve opening size for which 90 percent of the grains are smaller, is typically used for this purpose. The d_{90} size can be used as an acceptable approximation for the d_{eq} size of the largest particle in the bed. It is necessary to know the density of the media particles, and this can be done by running a specific gravity test on the media. This is especially important in multimedia applications where a lighter media is used as a cap. The fluidizing velocity depends on the temperature of the water as well, since the density and viscosity of the water are factors of the equations. Higher water temperatures require higher fluidizing velocities. Once the required fluidizing velocity is calculated, a safety factor of 1.3 is normally used to assure that an adequate wash rate is provided.

$$V_{mf} = \frac{R_{emf}\,\mu}{d_{eq}\,\rho}$$

R_{emf} = *Reynolds No. at minimum fluidization =*

$$[(337)^2 + 0.0408Ga]^{0.5} - 33.7$$

$$Ga = Galileo\ No. = \frac{d_{eq}^3 \rho (\rho_s - \rho)\ g}{\mu^2}$$

where:
V_{mf} = *fluidizing velocity, m/s*
p = *fluid density, kg/m*^{3}
p_s = *grain density, kg/m*^{3}
μ = *absolute viscosity, kg/m•s*
d_{eq} = *equivalent spherical diameter, m*
g = *gravity constant, 9.8 m/s*^{2}

Figure A-10 is a graph of the backwash rate required for fluidization of a sand media with an effective size of 0.48 mm (d_{90} = 1.0 mm) and a uniformity coefficient of 1.5 at varying water temperatures. As shown, the backwash rate varies significantly from a rate of 476 L/(min m^2) (11.7 gpm/ft^2) at a water temperature of 5°C (41.0°F) to approximately 820 L/(min m^2) (20.1 gpm/ft^2) at 30°C (86°F). Backwash facilities must be designed to provide the backwash rate required at the maximum process water temperature or the rate required by the regulatory body having jurisdiction over the project.

C. Continuous Backwash Filtration

1. Description of Unit

Two types of continuous backwash systems are commercially available; the travelling bridge filter and the upflow or downflow deep bed granular media filter.

The travelling bridge filter is a gravity filter divided up into several individual filter cells. A hood travels horizontally along the cells, backwashing individual cells while the other cells continue to filter water. The influent floods the bed, flows via gravity through the media and exits through effluent ports. Typically, the media bed is approximately 300 mm (11 inches) deep and may consist of single or dual media. Surface filtration, versus depth filtration, is achieved by the filter.

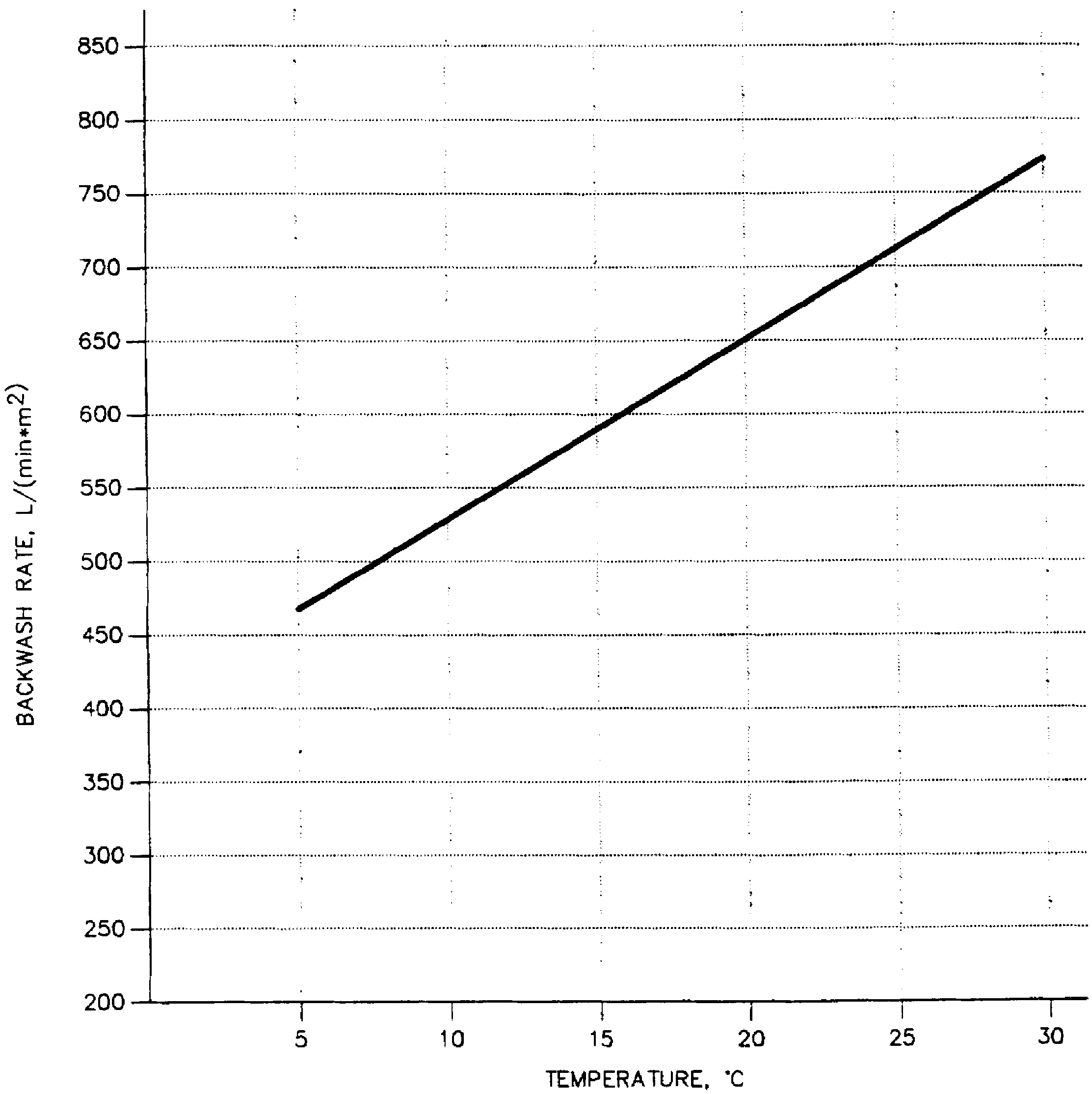


FIGURE A-10. BACKWASH RATE CURVE FOR FLUIDIZATION SAND MEDIA, ES OF 0.48 mm, U.C. OF 1.65.

Surface filtration occurs due to the low terminal head loss (usually less than 0.5 meter (2 feet)). Concurrent with the filtering operation, a hood travels along a track system. The hood isolates an individual cell for backwashing. A backwash pump draws filtered water from the effluent chamber, pumping the water back through the effluent port to fluidize and backwash the bed. Another pump picks up washwater collected in the hood and discharges it to the washwater trough. No air scour or hydraulic spray jets are used to supplement backwash, but a scarifier blade plows the media and loosens the solids mat as the hood moves into position to backwash. Backwash may be initiated by a triggering head loss measured by water level probes, automatically based on a preset timer, or manually. Figures A-ll and A-12 show a travelling bridge filter system. (Aqua-Aerobic Systems, Inc., Infilco Degremont, Inc.)

The upflow continuous backwash granular media filters are proprietary systems. The media is housed in a cylindrical tank. Water enters the lower part of the filter tank and moves upward, contacting the granular filtration media. Each manufacturer has its own influent dosing mechanism, by which the influent stream is introduced to the filter bed. Generally, effluent is discharged over an effluent weir. Concurrent to filtration, the media is constantly moving downward, removed from the filtration zone for washing, and returned to the top of the filtration zone when clean. The media is removed from the filter bed by means of an eductor pipe. The eductor pipe provides sufficient suction to the media bed to draw the filter sand from the system. Compressed air is generally introduced at the bottom of the pipe, causing the media to be drawn from the bed upward to the washer unit. In addition to providing transport, the eductor tube, or airlift system, provides air scour of the media. The media undergoes an additional cleaning step. The more common configuration uses a washbox located within the filter tank. A percentage of filtrate is allowed to flow upward into the washbox. The washbox is baffled, allowing for counter-current washing and gravity separation of the cleaned sand and the concentrated waste solids. Solids generally are discharged through a reject pipe for disposal. Alternatively, the media may be cleaned in a separate washer unit. This type of system may not require compressed air for operations. Instead, water is used in the eductor pipe for transport of sand to the media wash unit. The wash process consists of a number of co-current media washes by filtered water within the baffled media washer. Figure A-13 shows a typical upflow continuous backwash system configuration. (Andritz Sprout-Bauer, Inc., Eimco, Parkson Corporation)

The downflow granular media continuous backwash filter is also a proprietary system. Influent enters at the top of the filter

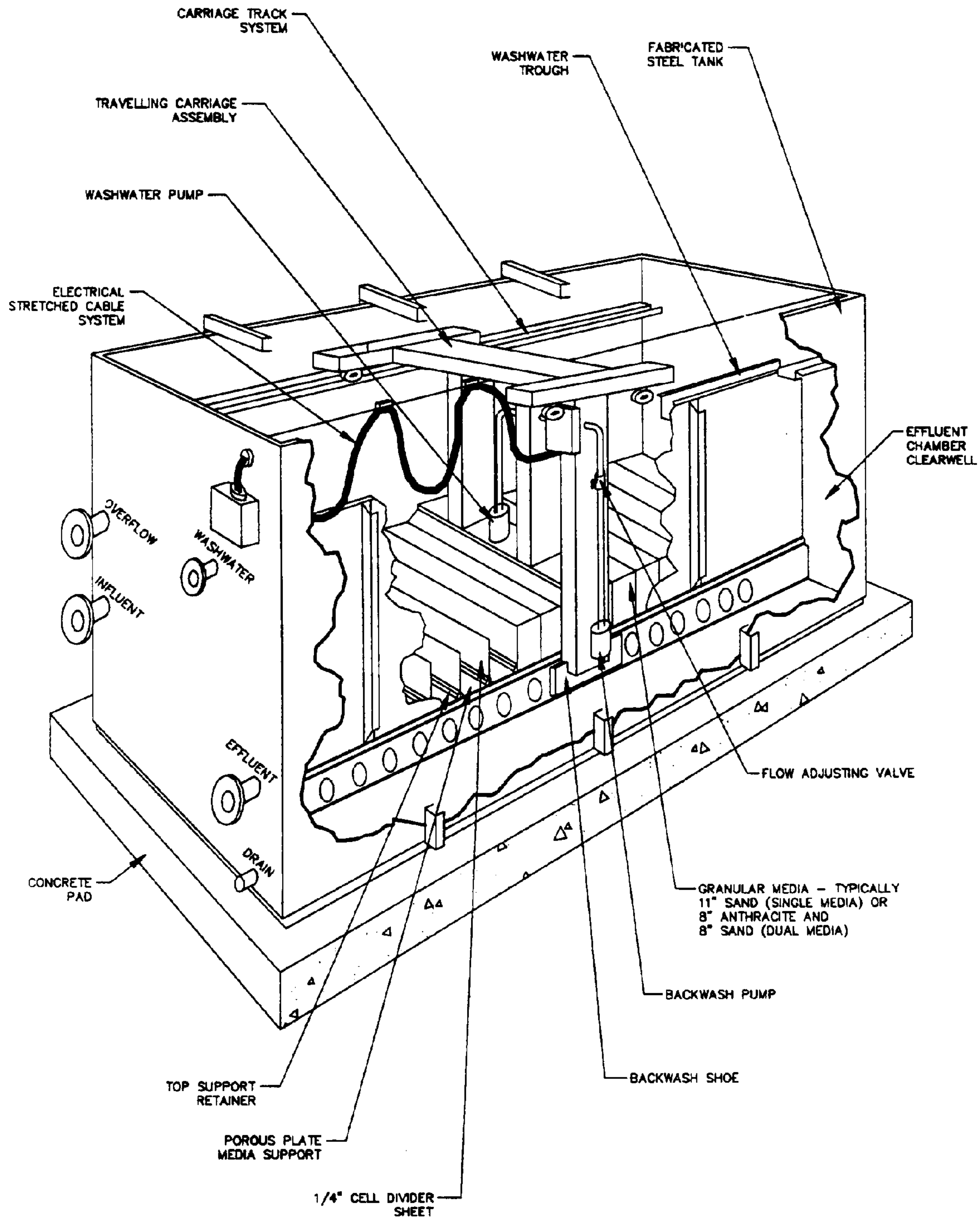


FIGURE A-11. TRAVELING BRIDGE FILTER

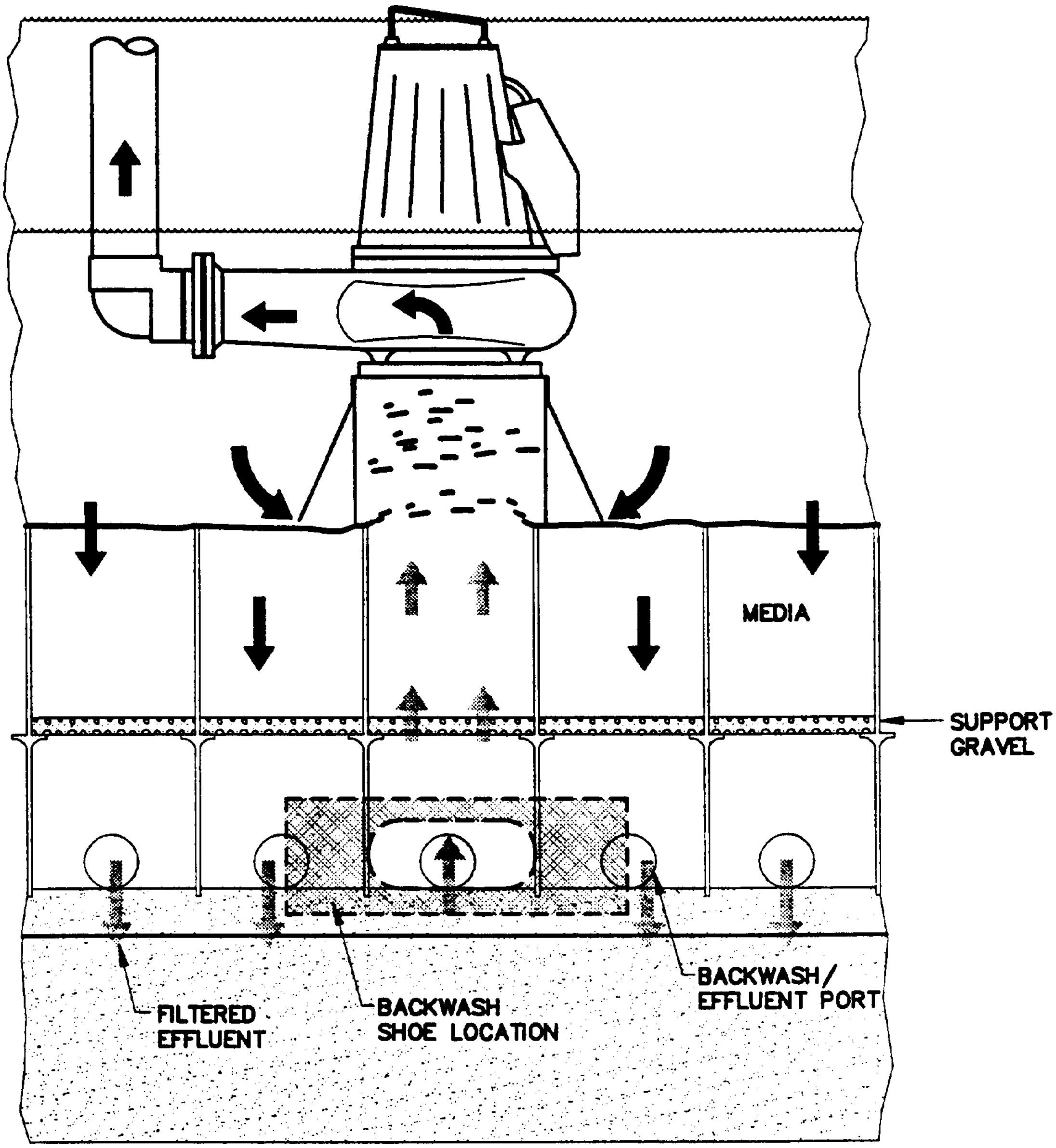


FIGURE A-12. TRAVELING BRIDGE FILTER

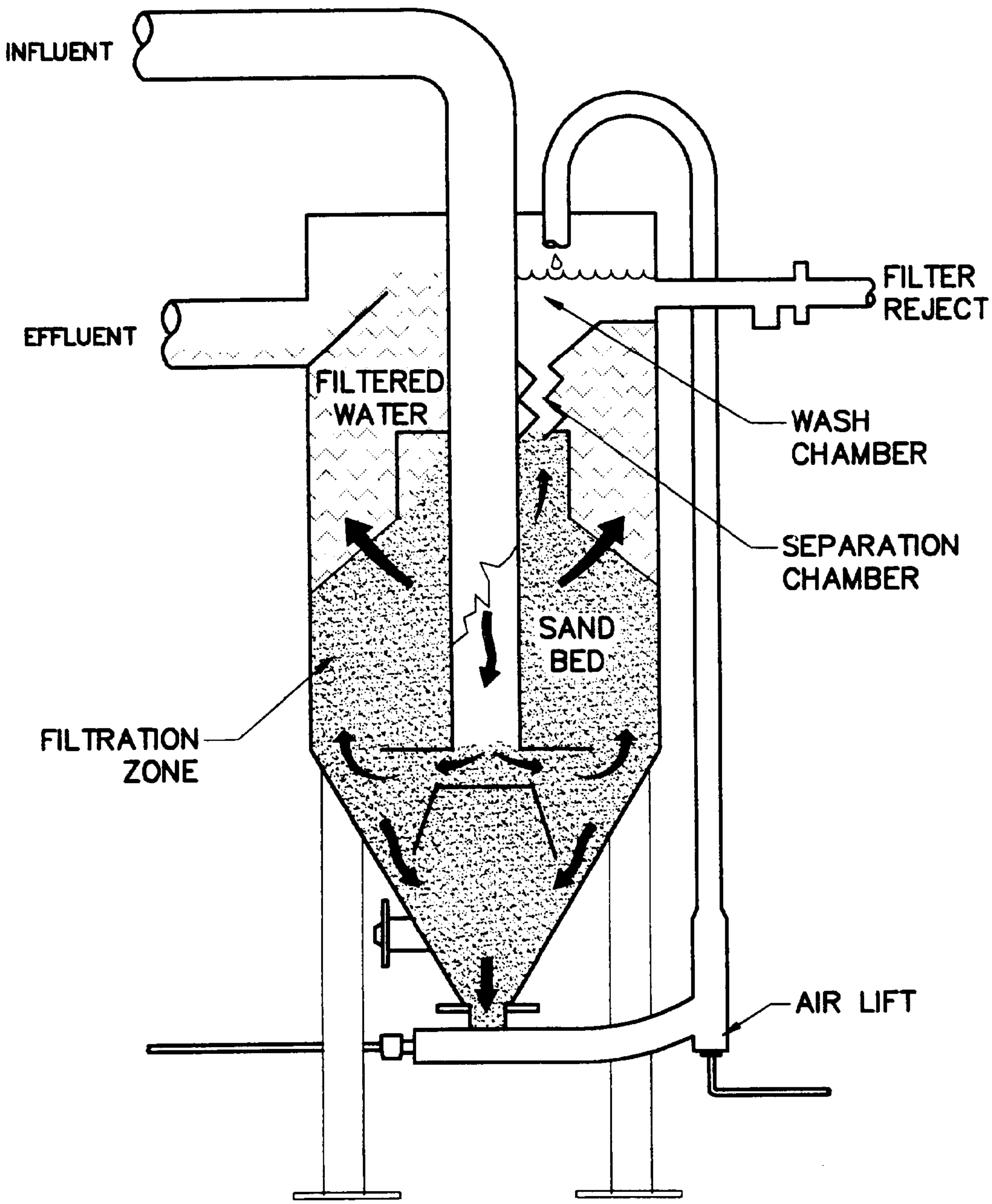


FIGURE A-13. UPFLOW CONTINUOUS BACKWASH FILTER

module (several modules are grouped together to create the filter cell, whose size and shape will be determined by flowrate). The influent passes through layers of increasingly finer sand, enters a filtrate chamber and is discharged. The coarse-to-fine gradation occurs as clean sand falls from the washbox to the top, and center, of the filter bed. The coarsest sand "rolls" to the periphery of the filter cell while the finest particles remain at, or near, the peak of the filter bed. This grading process is the result of gravity's effect on the varying sizes of sand as it seeks its natural angle of repose. The coarse-to-fine gradation is maintained throughout the depth of the filter as the airlift pump continually removes the lowest layer of sand for cleaning. The airlift tube assembly transports the sand media and captured solids to the top of the filter. The turbulence within the assembly separates the sand from the solids. Both sand and solids are placed into a sand washer chamber, which operates in essentially the same manner as that employed by the upflow system. The heavier sand falls back into the sand bed and the solids are discharged through the reject pipe. Figure A-14 shows a typical downflow continuous backwash system configuration. (Ashbrook-Simon-Hartley Corporation)

2. <u>Media Configuration</u>

The frequency of backwash and filter configuration for both the travelling bridge and deep bed filters allow for silica sand to be used effectively as a single media. Regarding travelling bridge filters, silica sand can be used as a single medium since surface filtration is the primary method of solids removal within the filter. The frequency of backwash makes this practicable. Surface filtration allows the travelling bridge filter media bed to be relatively shallow. Typical bed depths are approximately 300 mm (11 inches).

Continuous backwash filtration systems successfully use silica sand as a single medium. Traditional common problems associated with use of a single medium are avoided since the bed is continuously moving. The absence of a backwash cycle results in no stratification of the bed. Also, surface straining and resultant solids matting and head loss buildup is avoided. However, one drawback of the continuous backwash system is generally higher suspended solids in the effluent as compared to gravity or pressurized granular media filters. Typically, continuous backwash filters maintain a bed of approximately 1 m (40 inches), with sand approximately 1.2 mm in diameter. Deeper and shallower beds are available from certain manufacturers for appropriate applications.

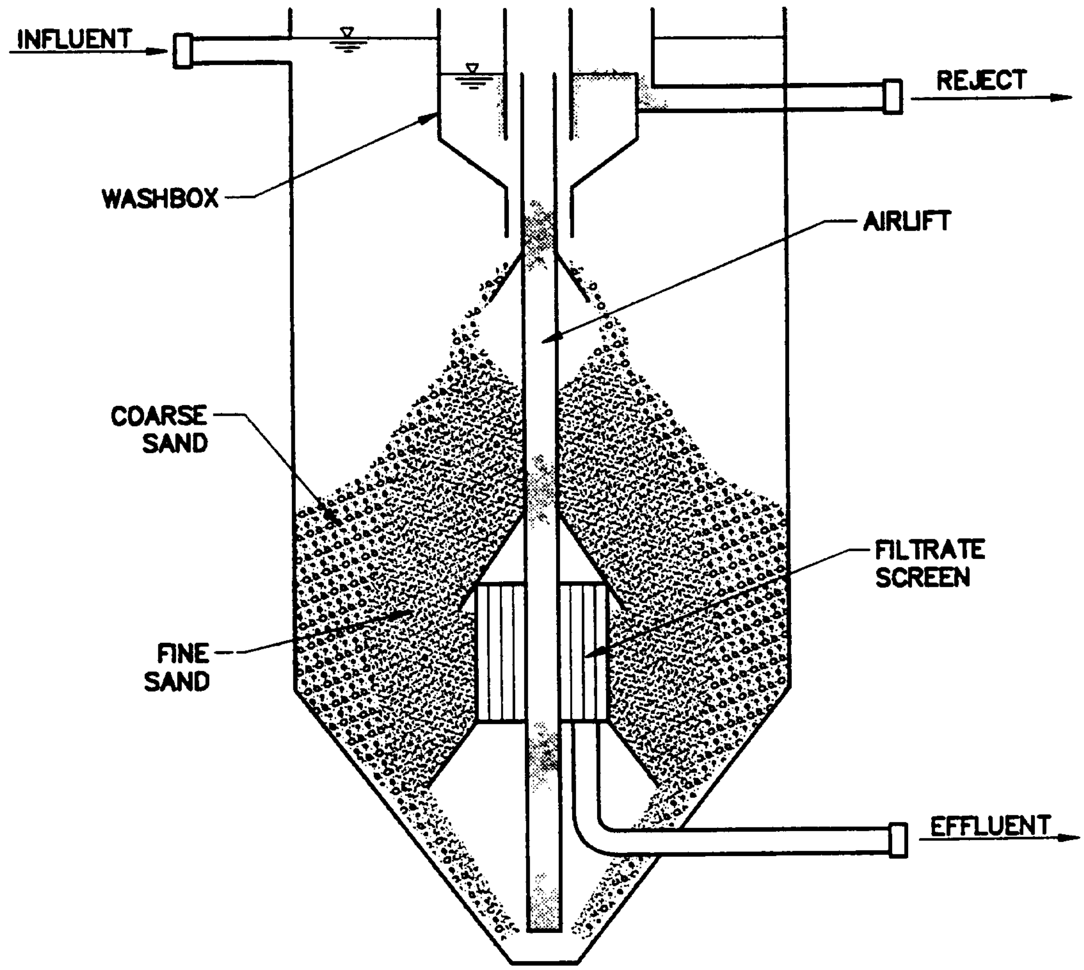


FIGURE A-14. DOWNFLOW CONTINUOUS BACKWASH FILTER

3. Underdrain

Travelling bridge filters generally use porous plate underdrains with no gravel layer. The porous plate is advantageous for this application since no air scour is needed to supplement water backwash due to backwash frequency and no gravel is required, helping to minimize total bed depth. (Aqua-Aerobic Systems, Inc.; Infilco Degremont, Inc.)

No support system is required for downflow and upflow continuous backwash systems since the media moves through the filter shell. This eliminates the need for both media support and backwash distribution, the purposes of the underdrain.

4. Design Considerations

In addition to the filter tank, media, media support, distribution and collection devices and the necessary controls, the travelling bridge filter also has the travelling backwash hood and rail upon which it moves. Travelling bridge filters are proprietary systems. The systems are constructed of concrete or steel. The bridge design and construction can vary substantially based on the hood itself and the transport system. The filter bed is divided horizontally into several cells. Each cell operates as a gravity filter. Backwashing occurs under the hood. Backwash can be performed automatically or based on a triggering mechanism. Package filtration systems are commercially available.

All continuous backwash filters are proprietary systems. The manufacturers offer systems which operate at a range of capacities. Generally, the filters use a single medium (sand) which is housed in a cylindrical shell. These shells may be stand-alone units or multiple units may be housed in a concrete tanks if the influent flow warrants. The systems can be manufactured from a variety of materials, ranging from mild-steel with various coatings to fiberglass reinforced plastics to stainless steel. Several different size upflow and downflow continuous backwash systems are commercially available. The systems treat throughput ranging from approximately 1 LIs through 6 L/s (14 gpm through 1000 gpm). Travelling bridge systems are similarly sized. Since backwash is continuous there is no limiting head loss or breakthrough conditions which must be determined.

The shell of the upflow and downflow continuous backwash systems generally house the media, media distribution system to re-inject the media into the bed after washing, the media removal system to remove the media requiring cleaning from the bed, and influent, effluent and reject wash water distribution systems, weirs and lines. Additionally, the systems will have a media cleaning system located either external to or within the filter shell.

5. Backwash

Travelling bridge systems are designed such that individual gravity filter cells may be backwashed while the remaining cells continue to filter influent water. Backwashing occurs underneath a hood which is suspended below the bridge or carriage. The hood moves slowly along the filter system. Filtering flow out of each cell through the effluent port is slowly blocked off by the backwash shoe frame. Concurrently, backwash flow into the cell is slowly increased as the shoe moves over the cell. When the shoe completely isolates the cell, full backwash flow occurs. Then, backwash flow is slowly reduced as the shoe moves off the cell, and filtering resumes. The backwash pump draws filtered water back through the effluent port to backwash the cell. Another pump picks up washwater collected in the hood, and discharges it to a washwater trough. Backwash may be triggered by head loss (water level probes), automatically (timer), or manually. Typical reject rates are range from 3% and 5%.

Continuous backwash systems allow for continuous system operation by cleaning the used media in a washer unit located separate from the media. In downflow and upflow continuous backwash systems, the media moves within the bed to a removal port and is then washed via air scour and/or water before re-injection into the bed. This is generally accomplished using an eductor pipe, compressed air system, sandwasher chamber, and reject line. The turbulence within the tube scours the solids from the media. The solids are then separated from the media grains in a separation or washer chamber. Alternatively, the media may be washed in an external media washer to separate the solids from the media. The media washer is basically a baffled chamber which uses gravity separation to separate the solids from the media. The baffles allow for countercurrent washes. Upward flowing water results in sluicing away low density solids, and settling of the media. After being washed, the media is returned to the filter shell. Reject rates for continuous backwash systems typically range between 2% and 15% of the feed stream flow rate, but may be up to 25%. Because continuous backwash systems have a continuous waste stream they are not used as a primary or the only treatment process at HTRW sites. They are almost exclusively used in conjunction with an upstream clarification unit to handle solids returned from the reject stream.

D. Advantages/Disadvantages

Gravity filtration systems are the simplest granular media filtration systems. Reasonably long filter runs can be achieved, but there is the possibility of negative gauge developing within the filter bed, resulting in "air binding." Air binding problems typically result where particle removal is occurring in only the top few inches of the filter bed and the entire depth of the bed is not being used for removal. When the head loss at any level in the filter exceeds the static head to that point, a head condition below the atmospheric level (vacuum or negative gauge) occurs. This is commonly referred to as a negative head condition and can cause air binding of the filter. When a negative head condition occurs, dissolved gases in the water are released and gas bubbles are formed within the filter bed. These trapped gas bubbles cause additional head losses aggravating the problems even further.

Negative gauge pressure is generally absent in pressure filtration systems. Pressure filtration systems can be operated at higher terminal head losses, which generally result in longer filter runs and reduced backwash requirements. High power costs are associated with pressure filtration systems, indicating their practicality is limited by cost considerations. Additionally, because the elements are enclosed in a steel shell, access for normal maintenance and observation is limited.

Travelling bridge filters offer the advantages of gravity filtration, plus the additional advantage of no periodic system shutdown for backwash since the individual cell backwash does not impact filtration ability. Additionally, no backwash holding tanks are required, since backwash water is obtained from the effluent chamber, and the filter can use a single medium. But extensive maintenance (electric gear motors, drive shafts, bearings to lube and maintain) has been associated with the travelling bridge filter. The traveling bridges have also suffered alignment problems.

The continuous filters are deep bed design, allowing for maximum solids capture. Continuous backwash systems also offer the advantage of avoiding periodic backwash cycles. This results in continuous, steady state operation with constant pressure drop, and also eliminates the auxiliary equipment associated with the backwash process. But, alternative equipment and systems must be installed and operated to clean the media. For example, special influent dosing mechanisms, the washer chamber, the compressed air system, and the sand lift mechanism must be provided. In practice, biological fouling of the filtrate stream on the downflow system and problems with the upflow system's ability to handle high influent solids loading have been reported.

Certain states are no longer giving approval for operation of continuous backwash systems for potable water applications. Especially with regard to the travelling bridge system, but also to a degree with the upflow system, the potential for contact between influent and effluent water creates a disinfection issue. Similar considerations may be an issue with HTRW applications. Potential cross-contamination is also an issue when dealing with hazardous waste water as when dealing with potable water. Specifically, the most common complaints object to a single wall between filtrate and unfiltered water, no air scour and/or water wash, no water to waste after backwash, insufficient media depth, and open filtrate channel.

E. Reference. See Appendix D.